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ORIGINAL ARTICLE

Effects of raw and diluted municipal sewage effluent with micronutrient foliar sprays on the growth and nutrient concentration of foxtail millet in southeast Iran

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Abstract In this study, the effect of irrigation with raw or diluted municipal sewage effluent accompanied by foliar micronutrient fertilizer sprays was examined on the growth, dry matter accumulation, grain yield, and mineral nutrients in foxtail millet plants. The experimental design was a split plot with three irrigation sources: raw sewage, 50% diluted sewage, and well water comprising the main treatments, and four combinations of Mn and Zn foliar sprays as sub-treatments that were applied with four replications. The experiment was conducted in 2009 at the Zabol University research farm in Zabol, south Iran. The applied municipal sewage effluent contained higher levels of micronutrients and macronutrients and exhibited greater degrees of electrical conductivity compared to well water. Because of the small scale of industrial activities in Zabol, the amount of heavy metals in the sewage was negligible (below the limits set for irrigation water in agricultural lands); these contaminants would not be severely detrimental to crop growth. The experimental results indicated that irrigation of plants with raw or diluted sewage stimulates the measured growth and productivity parameters of foxtail millet plants. The concentrations of micronutrients and macronutrients were also positively affected. These stimulations were attributed to the presence of high levels of such essential nutrients as N, P, and organic matter in wastewater. Supplied in sewage water alone, Mn and Zn were not able to raise the productivity of millet to the level obtained using fertilizers at the recommended values; this by itself indicated that additional nutrients from fertilizers are required to obtain higher levels of millet productivity with sewage farming. Despite the differences in nutrient concentrations among the different irrigation water sources, the micronutrient foliar sprays did not affect the concentrations of micronutrients and macronutrients in foxtail millet plants. These results suggested that municipal sewage effluent could be utilized efficiently as an important source of water, and that the nutrients used in growing foxtail millet with

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sewage water irrigation did not have any significant harmful effect on crop productivity. In contrast, the nutrients proved beneficial to soil fertility and millet productivity and quality.

1. Introduction

Iran is a predominantly arid country. Shortage of fresh water, especially in the arid and semi-arid regions of southeastern Iran, is the main barrier to proper management of soil resources, which would maximize cropping intensity and produce higher crop yields (Salehi et al., 2008). The region in which the present research was conducted, Zabol (a city located in southeastern Iran), suffers from a deficient water balance, particularly during the summer months, because of increased agricultural activity and higher ambient temperatures. The total irrigated area in this region is approximately 26,000 ha (Department of Agriculture, Zabol, personal communication). This area is now partly irrigated with scarce water resources. The surface water of the Hirmand River is shared between Iran and Afghanistan, and its branches are the main sources for the domestic, industrial, and agricultural sectors in this region. The scarcity of water resources in this area is expected to become more severe in the coming years, primarily because of the growing consumption of water in Afghanistan and also because of climate change. Therefore, one of the challenges facing agriculture in this region is to find new sources of water for irrigation. As a result of the freshwater crisis in the Zabol district, the reuse of treated sewage effluent in agriculture is receiving more recognition as a potential water source.

Effluents from municipal sewage treatment plants often contain high levels of plant nutrients, particularly N and P that are essential to crop growth. Agricultural applications of effluent could provide water and nutrients for crop production (Chambers et al., 2002), and the nutrient enriched sewage effluent could substantially reduce the reliance on chemical fertilizers (Wang and Tao, 1998). However, depending on the source of the sewage, it may contain potentially harmful components such as heavy metals and pathogens, which can accumulate in soil and biological systems and prove hazardous (Rattan et al., 2005). Therefore, when sewage is used on land for irrigation purposes, the problems associated with its use should be considered (Emongor and Ramolemana, 2004).

A number of investigators (Salehi et al., 2008; Mohammad and Ayadi, 2004; Ali et al., 2010; Kaneker et al., 1993; Abbaas et al., 2002; Berbec et al., 1999) have reported that municipal sewage effluent can be used for crop production. Furthermore, proper management practices in the use of such water and in the selection of crop will minimize deleterious effects on soil properties and crop yields (Pathak et al., 1999; Ali et al., 2010; Hassan et al., 2002; Guo and Sims, 2000).

Foxtail millet (*Setaria italica*) is a major crop grown in the arid areas of Iran. It was selected for this study because of important attributes such as tolerance to a wide range of soil types and pH, as well as rapid growth and high biomass yield (Sreenivasulu et al., 2004).

Different doses of effluent have been examined in combination with different types of chemical fertilizers in agricultural fields, and there are reports of both positive and negative effects. For example, Joshi et al. (1998) recommended four post-sowing irrigation with diluted effluent in combination with a 50 NPK treatment to achieve the best results. The majority of such studies has focused on macronutrients, and to our knowledge, there are no studies have been conducted on the impacts of effluent on plant response to micronutrients application.

Other studies (Salehi et al., 2008; Ali et al., 2010; Hassan et al., 2002; Mohammad and Ayadi, 2004) have shown that the effect of one effluent may vary from crop to crop, depending on differences in climate, vegetation, and social and cultural conditions, as well as on the changes in the qualities of soils and sewage among different regions and within different time periods in one region. Consequently, it is essential to study the effects (positive, negative, and neutral) of effluent on individual crops before their dispersal in agricultural fields. The objective of this study was to quantify the potential effects of irrigation with raw and 50 diluted effluent accompanied by micronutrient foliar application (Zn and Mn) on millet crop growth, yield, and nutrient accumulation in the Zabol district.

2. Materials and methods

2.1. Site description

The field experiments were conducted in 2009 on an agricultural farm in Zabol University (61°29′N, 31°2′E, 450 m above sea level) in southeast Iran. The experiment was performed in a sandy loam soil [19 clay (<2 μm), 21 silt (2–20 μm), 41fine sand (20–200 μm), and 19 coarse sand (200–2000 μm)], with a pH of 7.8, organic mater 0.11, N–NO_3 2.9 ppm, P (Olsen) 2.2 ppm, and K 156 ppm (0–30 cm depth)].

The experimental site is located in a warm and arid region with a mean annual precipitation of 63 mm and an annual mean long-term average temperature of 23 °C. In 2009, the year this experiment was conducted, the annual precipitation and mean temperature were 98 mm and 20 °C, respectively. These values differed considerably from the long-term average. Precipitation and mean temperature were, respectively, above and below the long-term average. The preceding crop was forage sorghum (*Sorghum bicolor*), and there was no history of sewage application at the site of the experiment.

2.2. Experimental layout

Seedbed preparation included plowing, disk harrowing, and cultivating. Foxtail millet (*Setaria italic* L.), KMF9, used in this experiment was released by the Seed and Plant Improvement Institute of Iran. The experimental design for this study was a split plot with a randomized complete block design and four replicates. Main plot treatments comprised the application of three types of irrigation water (well water, 50 diluted municipal sewage effluent and raw municipal sewage effluent). Subplot treatments consisted of four combinations of foliar micronutrient fertilizer sprays: treatment A0: no foliar fertilizer (tap water spraying); treatment A1: foliar fertilization with $MnSO_4$ (34.2 Mn) in a dose of 850 mg l^{-1} (1.02 kg ha^{-1} of $MnSO_4$);

treatment A2: foliar fertilization with $ZnSO_4$ (38.4Zn) in a dose of 850 mg l^{-1} (1.02 kg ha^{-1} of $ZnSO_4$); and treatment A3: foliar fertilization with a combination of $ZnSO_4$ and $MnSO_4$ (1.02 kg ha^{-1} of $ZnSO_4$ and 1.02 kg ha^{-1} of $MnSO_4$). The treatments were performed in 5×6 m plots, and the crops were sown with 0.50 m space between the rows and 0.10 m space between the plants, giving a plant density of 200,000 plants ha^{-1}.

The first spraying was carried out 4 weeks after the plantation. The foliar fertilizer was applied using a hand-operated knapsack sprayer. The plots were sprayed during late afternoon or evening hours when the wind speed was less than 10 km h^{-1}, and the air temperature was lower than 25 °C. For preparation of the spraying solutions, good quality tap water (EC: 0.25 mmhos cm^{-1}, pH: 7.14) was used; the control plants were sprayed with tap water (0 mg Mn or Zn l^{-1}); approximately 600 l of spray solution was applied per hectare; a second spraying was carried out 4 weeks after the first application using the above mentioned spraying method.

Irrigation scheduling was based on the soil moisture deficit in the root zone at each irrigation site (the difference between the root zone soil water at field capacity and at irrigation time) with 4-day intervals. To determine the soil water deficit within the root zone, the depth of rooting was measured weekly, and the soil water content was measured using a gravimetric method 1 day before each irrigation period at the middle of the laterals and the furrows and between the crop rows in all treatments.

The seeds of crops were sown manually on May 7, 2009. Adjacent subplots were separated by a 0.5-m ridge, and the main plots were separated by a 2-m ridge. All plots were given 100 kg P_2O_5 ha^{-1} as the triple superphosphate, and 50 kg potassium sulfate ha^{-1} together with half of the N fertilizer (25 kg ha^{-1}) were uniformly broadcasted and plowed 15 cm into the soil before sowing. The other half of the N fertilizer was applied with irrigation approximately 30 DAP. During the growth period, all plots were weeded manually. No serious incidents of insects or diseases were observed, and no pesticide or fungicide was applied.

2.3. Plant sampling and growth analysis

At the end of the growth period, 5 plants were sampled and the panicle number per plant, grain number per panicle, panicle length, and one-thousand grain weight, as well as vegetative growth parameters including stem height, collar diameter, and panicle length, were separately recorded.

2.4. Analysis of plant and irrigation waters

Harvested samples of plants were washed and oven-dried at 55 °C for 72 h, and the dried plant parts were ground to powder. For each plant sample, 1.0 g of powder was digested with 10 N HNO_3, and the sample digests were subjected to element analysis by an atomic absorption spectrophotometer (Shimadzu, AA-670). A flame photometer (Jenway, PFP7) was used to determine the Na and K contents.

After collection, the sewage effluent and well water were stored in ordinary plastic bottles. Irrigation quality criteria, including pH and EC, were assessed using procedures described by USSL (1954), DO, BOD, COD, cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), anions (Cl^{-}, NO^{3-}), NH_4–N, and P as given by APHA–AWWA–WEF (1995). Micronutrients and heavy metals such as Fe, Cu, Mn, Zn, Pb, Cd, and Ni were estimated after wet digestion with a 1:4 $HClO_4$:HNO_3 mixture, followed by the measurement of respective concentrations using the atomic absorption spectrophotometer.

2.5. Statistics

Data collected were subjected to analysis of variance. *t*-Test was used to determine the significance of the treatment difference. The significant differences between treatments were compared with the critical difference at a 5 level of probability.

3. Results

3.1. Sewage effluent

The qualities of municipal sewage effluent and well water were assessed for irrigation with respect to their pH, EC, DO, BOD, COD, and concentrations of nutrients and heavy metals (Table 1). Results indicated that all sampled waters were alkaline. The pH of the municipal sewage effluent (pH 7.6) was lower compared to that of the well water (pH 7.7), whereas the effluent's salt content (EC 1.65 dS m^{-1}) was considerably higher compared to that of the well-waters (0.34 dS m^{-1}); this indicated that the sewage effluent was saline in nature. As expected, the sewage water exhibited low levels of dissolved oxygen (3 mg l^{-1}) compared to the well water (9 mg l^{-1}). The effect of DO was reflected on BOD of the samples; its value was quite high in raw sewage (89 mg l^{-1}), although its value was only 2 mg l^{-1} in the well water. Sewage effluent exhibited a very high COD value (191 mg l^{-1}), whereas the amount of COD in the well water was negligible (8 mg l^{-1}). BOD and COD of the sewage effluent were rated as suitable for irrigation purposes compared with the prescribed limits of 100 and 250 mg l^{-1} for BOD and COD, respectively (ISI, 1987).

Table 1 Characteristics of sewage effluent and well-water.

Parameters	Units	Sewage effluent	Well-water
pH		7.6	7.7
EC	(dS m^{-1})	1.65	0.34
DO	(mg l^{-1})	3	9
BOD	(mg l^{-1})	89	2
COD	(mg l^{-1})	191	8
Na	(mg l^{-1})	123	32
K	(mg l^{-1})	20	31
Ca	(mg l^{-1})	257	95
Mg	(mg l^{-1})	151	42
Cl	(mg l^{-1})	187	7.5
PO_4–P	(mg l^{-1})	18.7	ND
NH_4–N	(mg l^{-1})	6.5	1.2
NO_3–N	(mg l^{-1})	1.5	0.02
Zn	(mg l^{-1})	0.71	0.03
Fe	(mg l^{-1})	1.06	0.02
Mn	(mg l^{-1})	0.61	0.11
Cu	(mg l^{-1})	0.34	0.03
Cd	(mg l^{-1})	4.2	0.01
Pb	(mg l^{-1})	0.02	ND
Ni	(mg l^{-1})	0.24	ND

ND, not detected; EC, electrical conductivity; DO, dissolved oxygen; BOD, biochemical oxygen demand, and COD, chemical oxygen demand.

Table 2 Effects of different irrigation sources (well-water, 50% diluted and raw effluent) and foliar micro-nutrients spraying on vegetative growth parameters, yield and yield attributes of foxtail millet.

Treatment	Stem high (cm)	Collar diameter (mm)	Panicle length (cm)	1000 grain weight (g)	Panicle ($plant^{-1}$)	Grain ($panicle^{-1}$)	Biological yield (kg ha^{-1})	Grain yield (kg ha^{-1})
Irrigation source treatments								
Well-water	74.08c	4.71b	7.30c	1.96a	2.33b	824.00c	744.33c	6137.44a c
50% Diluted sewage	81.33b b	5.19a	8.28b	2.01a	2.48a	878.17b	827.33b	6796.02b
Raw sewage	88.33a	5.28a	9.10a	2.03a	2.62a	936a	910.92a	7511.33a
Foliar micro-nutrients treatment								
Control	78.00c	4.94c	8.03c	2.00a	2.37b	861.67c	805.00c	6604.03c
Manganese	81.56b	5.04b	8.19b	1.98a	2.44a	881.22b	828.89b	6811.22b
Zinc	81.44b	5.04b	8.16bc	2.00a	2.47a	875.22b	814.44bc	6739.51bc
Zinc + manganese	84.00a	5.20a	8.53a	2.01a	2.49a	900.33a	861.78a	7105.82a
Two way ANOVA								
F-Value								
Irrigation	270.78	269.60	638.04	1.23	77.29	469.83	157.27	132.63
Micro-nutrients	24.34	24.07	27.08	0.15	4.37	28.61	10.50	9.47
P-Value								
Irrigation	< 0.0001	< 0.0001	< 0.0001	0.3162	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Micro-nutrients	< 0.0001	< 0.0001	< 0.0001	0.9286	0.0178	< 0.0001	0.0003	0.006

Means followed by a similar letter within a column are not significantly different at the 0.05 level probability by Duncan's Multiple Range Test. Results are an average of four replicates ± S.D.

The concentrations of all nutrients and heavy metals (N, P, K, Ca, Mg, Na, Fe, Cu, Mn, Zn, Cd, Ni, and Pb) were higher in the municipal sewage effluent than in the well water. The sewage contained appreciable amounts of useful major plant nutrients, such as N, P, K, and Ca, which were reflected in the appreciable build-up of these nutrients in the sewage-irrigated soils of our study area (Rattan et al., 2005). According to Pescod et al. (1992), the threshold values of heavy metals in irrigation water that lead to crop damage are 2000 mg L^{-1} for Zn, 200 mg L^{-1} for Cu, 5000 mg L^{-1} for Fe, 200 mg L^{-1} for Mn, 200 mg L^{-1} for Ni, 5000 mg L^{-1} for Pb, and 10 mg L^{-1} for Cd. Although the sewage effluent had elevated concentrations of some of the metals compared to the well water, the concentrations of such metals in this source of irrigation water were well within the permissible limits for their use as irrigation water, except for Cd. However, the Cd concentration was close to the maximum permissible limits recommended for land use by the World Health Organization.

3.2. Plant growth and yield

3.2.1. Vegetative growth

The results of the vegetative growth parameters (stem height, collar diameter, and panicle length) as affected by the different

Table 3 Irrigation sources and foliar micro-nutrients spraying interaction on vegetative growth parameters, yield and yield attributes of foxtail millet.

Irrigation source treatments	Foliar micro-nutrients treatment	Stem high (cm)	Collar diameter (mm)	Panicle length (cm)	1000 grain weight (g)	Panicle ($plant^{-1}$)	Grain ($panicle^{-1}$)	Biological yield	Grain yield
Well-water	Control	70.67	4.60	7.03	2.07	2.17	804.67	723.00	5951.11
	Manganese	74.00	4.73	7.17	1.97	2.23	825.67	742.33	6131.89
	Zinc	74.33	4.70	7.27	1.83	2.23	820.00	748.00	6165.77
	Zinc + Manganese	77.33	4.80	7.73	1.97	2.30	845.67	764.00	6300.99
50% Diluted sewage	Control	77.33	5.07	8.13	1.93	2.43	873.00	798.33	6525.90
	Manganese	82.00	5.13	8.30	2.00	2.47	877.33	830.33	6776.66
	Zinc	81.67	5.20	8.17	2.03	2.50	873.33	818.33	6777.39
	Zinc + Manganese	84.33	5.37	8.53	2.07	2.50	889.00	862.33	7106.68
Raw sewage	Control	86.00	5.170	8.93	2.00	2.50	907.33	893.67	7335.07
	Manganese	88.67	5.27	9.10	1.97	2.63	940.67	914.00	7525.12
	Zinc	88.33	5.23	9.03	2.13	2.67	932.33	877.00	7275.36
	Zinc + Manganese	90.33	5.43	9.33	2.00	2.67	966.33	959.00	7909.78
Two way ANOVA									
F-Value	I × M	12.39	10.72	6.48	4.40	0.92	5.98	11.61	10.32
P-Value	I × M	0.0350	0.0418	0.0494	0.0455	0.4284	0.0164	0.0371	0.0455

Results are an average of four replicates ± S.D.

irrigation sources and foliar micronutrient spraying are presented in Table 2.

Stem height, collar diameter, and panicle length differ among different irrigation sources. In this study, irrigation with raw municipal sewage effluent produced the largest plants (height: 88.33 ± 3.06 cm, collar diameter: 5.28 ± 0.12 cm, and panicle length: 9.10 ± 2.0 cm). Plants irrigated with raw sewage effluent had 19 greater height, 5 greater collar diameter, and 25 greater panicle length compared to those irrigated with well water.

Among the spray treatments, the least growth was observed in the plants sprayed with tap water. The combination of Mn and Zn in a foliar spray contributed to a greater plant growth compared to the other spray treatment. The greatest growth parameters (height: 84.00 ± 6.14 cm, collar diameter: 5.20 ± 0.32 cm, and panicle length: 8.53 ± 0.70) were obtained with a Mn and Zn foliar spray, whereas the lowest (height: 74.08 ± 2.57 cm, collar diameter: 4.71 ± 0.15 cm, and panicle length: 7.30 ± 0.30) growth parameters were obtained with the control (tap water spraying).

Significant interaction between irrigation water sources and micronutrient spraying was observed on the vegetative growth parameters (Table 3). In the partition of this interaction, it was evident that plants irrigated with raw or 50 diluted sewage effluent had significantly higher growth rates within the Mn, Zn, and Mn and Zn foliar applications compared to those irrigated with well water.

3.2.2. Yield attributes

Data related to foxtail millet plant yields and yield attributes are presented in Table 2. There were significant differences among various irrigation sources in the panicle number per plant and the grain number per panicle. The application of sewage effluent treatments significantly increased the panicle number per plant and the grain number per panicle compared with the control (well water). Yield attribute parameters of raw sewage effluent treatments were generally higher than those found with the 50 diluted sewage effluent treatments, whereas the well water treatments exhibited the lowest values. The one-thousand grain weight in plants irrigated with the raw sewage effluent was slightly higher than that produced in plants irrigated with the 50 diluted sewage effluent and well water; this difference, however, was not statistically significant.

Micronutrient spray treatments showed rather remarkable differences in the yield attributes (Table 2). Mn and Zn foliar spraying increased the panicle number per plant and the grain number per panicle of millet by 5.1 and 4.5, respectively, over those of the control. The size of grain with micronutrient foliar application treatments was very similar. Hence, plants grown using different micronutrients foliar sprays did not differ in one-thousand grain weight. Significant interaction between the irrigation water sources and foliar spray treatments on all studied yield attribute parameters was observed except for the panicle per plant (Table 3).

Grain and biological yields of plants were also significantly affected by irrigation with sewage effluent. Grain and biological yields for the plants irrigated with raw sewage were 9.2 and 9.9 greater, respectively, than the yields of the plants irrigated with 50 diluted sewage. The grain and biological yields of the plants irrigated with 50 diluted sewage were also 17.2 and 18.3 higher, respectively, than the control.

Mn and Zn foliar spraying increased the grain and biological yields by 7.0 and 6.5, respectively, compared with those of the control. Significant interaction between irrigation water sources and micronutrient spray treatments was observed for grain and biological yields (Table 3). Irrigation with raw sewage effluent along with Mn and Zn foliar spraying and irrigation with well water along with Mn and Zn foliar spraying exhibited the greatest and least grain and biological yields, respectively.

3.3. Nutrient concentrations in plants

Mean concentrations of micronutrients, macronutrients, and heavy metals in the dry matter after the irrigation treatments and micronutrient (Mn and Zn) spraying are presented in Tables 4 and 6.

Table 4 Effects of different irrigation sources (well-water, 50% diluted and raw effluent) and foliar micro-nutrients spraying on macro-nutrient concentrations of foxtail millet.

Treatment	N	P	K	Ca	Mg
Irrigation source treatments					
Well-water	24.92c	2.18c	9.15c	18.93c	3.00b
50% Diluted sewage	27.67b	2.53b	10.35b	22.40b	3.27ab
Raw sewage	30.83a	2.83a	11.50a	26.67a	3.43a
Foliar micro-nutrients treatment					
Control	27.67a	2.51a	10.37a	22.76a	3.26a
Manganese	28.11a	2.53a	10.37a	23.11a	3.23a
Zinc	27.89a	2.48a	10.37a	22.04a	3.22a
Zinc + Manganese	27.56a	2.51a	10.23a	22.76a	3.22a
Two way ANOVA					
F-Value					
Irrigation	164.65	75.78	242.49	93.78	40.47
Micro-nutrients	0.86	0.28	0.59	0.94	0.16
P-Value					
Irrigation	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Micro-nutrients	0.4821	0.8379	0.6323	0.4427	0.9239

Means followed by a similar letter within a column are not significantly different at the 0.05 level probability by Duncan's Multiple Range Test. Results are an average of four replicates ± S.D.

Table 5 Irrigation sources and foliar micro-nutrients spraying interaction on macro-nutrients concentration of foxtail millet.

Irrigation source treatments	Foliar micro-nutrients treatment	N	P	K	Ca	Mg
Well-water	Control	24.67	2.13	9.10	18.67	2.97
	Manganese	25.33	2.20	9.20	19.73	2.97
	Zinc	24.33	2.23	9.40	18.13	3.03
	Zinc + manganese	25.33	2.17	8.90	19.20	3.03
50% Diluted sewage	Control	27.67	2.57	10.30	22.40	3.30
	Manganese	28.00	2.53	10.20	22.93	3.20
	Zinc	27.67	2.50	10.40	21.87	3.20
	Zinc + manganese	27.33	2.50	10.50	22.40	3.37
Raw sewage	Control	30.67	2.87	11.70	27.20	3.50
	Manganese	31.00	2.87	11.70	26.67	3.53
	Zinc	31.67	2.70	11.30	26.13	3.43
	Zinc + manganese	30.33	2.87	11.30	26.67	3.27
Two way ANOVA						
F-Value	I × M	1.46	0.86	2.20	0.20	2.27
P-Value	I × M	0.2459	0.5408	0.0917	0.9733	0.0825

Results are an average of four replicates ± S.D.

Higher concentrations of total macronutrients (N, P, K, Ca, Mg, and Na) in plants were monitored in millet plants grown on plots irrigated with sewage effluent; the constant trend in their concentrations in decreasing order was as follows: raw sewage effluent, 50 diluted sewage effluent, and well water.

Macronutrient concentration in the plants did not differ after micronutrient foliar spraying. No statistically significant difference has been found to exist between the interaction of irrigation water sources and micronutrient foliar spray treatments on macronutrient concentrations (Table 5).

Total concentrations of micronutrients (Zn, Mn, Fe, B, Cu) and heavy metals (Cd, Ni, Pb) in plants after raw sewage effluent treatments were significantly higher than those found after 50 diluted sewage effluent treatments, whereas those with well water treatments had the lowest concentrations.

The concentrations of the above mentioned micronutrients and heavy metals in the plants did not differ significantly because of micronutrient spraying. Although not significant, plants sprayed with Mn and Zn had, in most cases, the lowest concentrations of all measured micronutrients and heavy metals, whereas the plants sprayed with tap water exhibited the greatest concentrations of micronutrients and heavy metals, except for Mn and Zn. Concentrations of Zn and Mn were drastically higher in the plants that received Zn or Mn as foliar applications. Ni and Pb were not detected in plant tissues.

There was no significant interaction between irrigation water sources and micronutrient foliar spray treatment in all measured micronutrients and heavy metals except for Mn and Zn (Table 7). Accordingly, the concentrations of Mn and Zn in plants irrigated with well water increased by higher

Table 6 Effects of different irrigation sources (well-water, 50% diluted and raw effluent) and foliar micro-nutrients spraying on concentration of micro-nutrients and heavy metals of foxtail millet.

Treatment	Mn	Zn	Fe	Cu	Cd	Na	Ni	Pb
Irrigation source treatments								
Well-water	117.67c	86.75c	191.75a	17.08c	0.00c	1.00b	ND	ND
50% Diluted sewage	135.42b	91.50b	176.92b	21.33b	1b	1.20a	ND	ND
Raw sewage	143.92a	95.67a	171.75b	26.33a	2.27a	1.30a	ND	ND
Foliar micro-nutrients treatment								
Control	98.89c	51.44b	183.67a	21.89a	1.51a	1.19a	ND	ND
Manganese	172.00a	51.67a	177.22a	21.67a	1.34ab	1.17a	ND	ND
Zinc	90.11d	130.56b	178.67a	21.44a	1.38ab	1.17a	ND	ND
Zinc + Manganese	168.33b	131.56a	181.00a	21.33a	1.39b	1.14a	ND	ND
Two way ANOVA								
F-Value								
Irrigation	167.51	17.98	247.41	224.06	768.80	61.71		
Micro-nutrients	1347.05	1427.13	1.36	0.48	2.03	0.65		
P-Value								
Irrigation	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001		
Micro-nutrients	< 0.0001	< 0.0001	0.2867	0.7030	0.1455	0.5913		

Means followed by a similar letter within a column are not significantly different at the 0.05 level probability by Duncan's Multiple Range Test. Results are an average of four replicates ± S.D.

Table 7 Irrigation sources and foliar micro-nutrients spraying interaction on concentrations of micro-nutrient and heavy metals of foxtail millet.

Irrigation source treatments	Foliar micro-nutrients treatment	Mn	Zn	Fe	Cu	Cd	Na	Ni	Pb
Well-water	Control	86.00	44.00	198.00	17.67	0.00	1.03	ND	ND
	Manganese	161.00	42.33	193.00	17.00	0.00	1.00	ND	ND
	Zinc	65.67	126.33	188.67	16.67	0.00	1.00	ND	ND
	Zinc + Manganese	158.00	134.33	187.33	17.00	0.00	0.97	ND	ND
50% Diluted sewage	Control	94.33	50.67	180.33	21.33	2.17	1.20	ND	ND
	Manganese	179.00	53.00	174.33	21.33	1.77	1.20	ND	ND
	Zinc	99.33	132.00	173.00	21.67	1.90	1.20	ND	ND
	Zinc + Manganese	169.00	130.33	180.00	21.00	1.97	1.20	ND	ND
Raw sewage	Control	116.33	59.67	172.67	26.67	2.37	1.33	ND	ND
	Manganese	176.00	59.67	164.33	26.67	2.27	1.30	ND	ND
	Zinc	105.33	133.33	174.33	26.00	2.23	1.30	ND	ND
	Zinc + Manganese	178.00	130.00	175.67	26.00	2.20	1.27	ND	ND
Two way ANOVA									
F-Value	I × M	13.89	5.89	1.08	0.28	1.09	0.16		
P-Value	I × M	< 0.0001	0.0015	0.0729	0.9379	0.4071	0.9834		

Results are an average of four replicates ± S.D.

degrees than the concentrations in plants irrigated with sewage effluent and the allied mixtures.

4. Discussion

The lesser stem height, collar diameter, and panicle length in the plants irrigated with well water compared to those irrigated with sewage effluent were probably attributable to the lower availability of nutrients, which may have negatively affected cell enlargement (and consequently, leaf size and leaf surface area) (Boyer, 1988). The increase in vegetative growth parameters suggested that applied treatments influenced the physiological processes, facilitated early leaf initiation, and resulted in a net increase in the number of leaves. The increase in the number of leaves may have facilitated the capture of more solar energy for metabolic use, fixed more CO_2, and produced greater photosynthates and growth. This hypothesis is supported by Ceulemans et al. (1993) and Myers et al. (1996).

The higher yields of millet crops with sewage application relative to well water application have been explained by many researchers who have reported that sewage effluent has a stimulatory effect on the vegetative growth of plants because of the enhanced fertility status of soil, increased organic matter in the soil, and the improved physical environment of the soil. All of these factors may have diminished the deleterious effects of Na on the plants (Al-Jaloud et al., 1995) and promoted better germination, root proliferation, and nutrient and water uptake by the crops and greater biomass and grain production (Mohammad and Ayadi, 2004 on forage corn; Pathak et al., 1999 on wheat; Kaneker et al., 1993 on *Acacia nilotica*; Hassan et al., 2002 on *Acacia saligna* and *Leucaenaleucocephala*; Berbec et al., 1999 on poplar; Guo and Sims, 2000 on *Eucalyptus globulus*; Abbaas et al., 2002 on *Casuarin aglauca*, *Taxodium distichum*, and *Populus nigra*; and Ali et al., 2010 on *Tipuana speciosa*).

The effluent nutrients supplied to the soil–crop system depends on the effluent quality and the amount applied during irrigation (Hayes et al., 1990), these factors generally vary throughout the year (Feigin et al., 1991).

Irrigation with either raw or 50% diluted sewage effluent resulted in higher concentrations of most nutrients in the millet plant tissues. As expected, this higher accumulation paralleled higher nutrient concentrations in the irrigation water (Marschner, 1986). However, the level of Fe in the tissues was reduced. Lower levels of Fe in plants irrigated with effluent were observed despite higher levels of Fe in the water (Tables 1). It is possible that the higher levels of Cl in the effluent reduced the absorption of Fe. Indeed, exposure of crops to salt stress has been proven to reduce Fe accumulation in plants (Santos et al., 2001). No chlorosis was apparent despite the low levels of total Fe in plants; it is possible that the higher levels of Zn and Mn in the effluent served to overcome the deleterious effects of high Cl in the effluent that reduces the availability or uptake of these metals into the plant.

Ni and Pb were not detected in plant tissues; this may be because of negligible amounts of heavy metals in municipal sewage effluent because the size and amount of industrial activities in Zabol region are small. However, effluents discharged from minor available industrial units (like batteries and dairy products manufacturers) are a matter of concern, because high concentrations of certain elements can be hazardous, and hence, the influence of these metals should be considered.

Because of the low dynamics of toxic heavy metals, they possibly accumulate in the lower parts of the plant such as the root and stem. Nevertheless, Madejón et al. (2006) reported the presence of some heavy metals in the leaves of olive and holm oak trees. In fact, the quantity of element absorption by a plant depends on several factors, including the total quantity of the elements applied through sewage application, the soil properties, and the type of plant (Bozkurt and Yarilga, 2003; Sharma et al., 2007).

The present study revealed that the effluent Mn and/or Zn input was not sufficient because the plants irrigated with sewage effluent exhibited increased increments of plant growth and yield under Mn and Zn foliar application. Smith and Peterson (1982) and Feigin et al. (1991) have also reported that effluents represent a partial nutrient source for plants, depending on the local climate and soil conditions. Moreover, the nutrient demand or accumulation curve is not coincident with the water demand curve for most plants (Bouwer and Idelovitch, 1987). Azevedo (1998) observed that lettuce plants grown in soil without fertilizer, when irrigated with fish effluent, produced 3 times more dry matter than those irrigated with well water, even though nutrients in the effluent were not sufficient to allow optimal plant growth. However, when fertilization supplied all plant needs, the effluent did not influence the yield significantly.

The concentrations of N, P, and K in plants among the foliar application treatments were somewhat similar, and plants grown using different treatments did not differ considerably in concentrations of the above mentioned nutrients. Nevertheless, micronutrient foliar application led to lower concentrations of Cu, Zn, Mn, Fe, Ca, and Mg in plants when compared with the control (though not significantly). The findings that foliar spraying with a Mn and Zn foliar application reduced the total concentrations of Cu, Zn, Mn, Fe, Ca, Mg, and K in plants were probably attributable to an increase in the production of biomass resulting from micronutrient applications, in spite of their low content in the soil and the dilution of the concentrations of these elements in the plant tissues. The study of Chapagain and Wiesman (2004) on N, NO_3, Ca, Fe, and Zn status following K foliar spray indicated that K application did not change the nutrient concentration in plants.

5. Conclusion

The application of municipal sewage effluent had a positive effect on the growth and production of foxtail millet in the nutrient-poor soil of the arid areas of southeast Iran, without an excessive accumulation of any toxic elements in plants. Thus, the efficient use of this type of municipal sewage effluent can effectively increase water resources for irrigation and may prove to be a boon for agricultural production. From this study, it can be concluded that sewage effluent, in addition to being a source of irrigation water, is a potential source of plant nutrients, and that effluent application can result in an increase in micro- and macro-nutrients in soils. The effect of the effluent was more pronounced when micro-nutrient foliar spraying was also used. Significant depletion of available Mn and Zn in intensively cultivated soils is likely to induce a lack of sustainability of soil productivity. Hence, Mn and Zn should be included in fertilization programs, including those which utilize municipal sewage effluent.

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